# A Multivariate Statistical Analysis of Spiral Galaxy Luminosities. I. Data and Results

Alice Shapley
California Institute of Technology,
Pasadena CA, 91125, USA

G. Fabbiano
Harvard-Smithsonian Center for Astrophysics,
60 Garden Street, Cambridge, MA 02138

P. B. Eskridge
Ohio State University,
Dept. of Astronomy,
140 W 18th Ave, Columbus, OH 43210

## ABSTRACT

We have performed a multiparametric analysis of luminosity data for a sample of 234 normal spiral and irregular galaxies observed in X-rays with the *Einstein Observatory*. This sample is representative of S and Irr galaxies, with a good coverage of morphological types and absolute magnitudes. In addition to X-ray and optical data, we have compiled H-band magnitudes, IRAS near- and far-infrared, and 6cm radio continuum observations for the sample from the literature. We have also performed a careful compilation of distance estimates. We have explored the effect of morphology by dividing the sample into early (S0/a-Sab), intermediate (Sb-Sbc), and late-type (Sc-Irr) subsamples. The data were analysed with bivariate and multivariate survival analysis techniques that make full use of all the information available in both detections and limits. We find that most pairs of luminosities are correlated when considered individually, and this is not due to a distance bias. Different luminosity-luminosity correlations follow different power-law relations. Contrary to previous reports, the $L_X - L_B$ correlation follows a power-law with exponent larger than 1. Both the significances of some correlations and their power-law relations are morphology dependent. Our analysis confirms the 'representative' nature of our sample, by returning well known results derived from previous analyses of independent samples of galaxies (e.g., the $L_B - L_H$, $L_{12} - L_{FIR}$, $L_{FIR} - L_{6cm}$ correlations). Our multivariate analysis suggests that there are two fundamentally strong correlations, regardless of galaxy morphology, when all the wavebands are analyzed together with conditional probability methods. These are the $L_B - L_H$ and the $L_{12} - L_{FIR}$ correlations. As it is well known, the former links stellar emission processes, and points to a basic connection between the IMF of low-mass and intermediate-to-high-mass stars. The latter may be related to the heating of small and larger size dust grains by the same UV photon field. Other highly significant 'fundamental' correlations exist, but are morphology-dependent. In particular, in the late sample (Sc-Irr) we see an overall connection of mid-, far-IR, and radio-continuum emission, which could be related to the presence of star-forming activity in these galaxies, while in early-type spirals (S0/a-Sab), we find no strong direct link of FIR and radio continuum. This paper gives a compilation of both input data and results of our systematic statistical analysis, as well as a discussion of potential biases. Results relevant to both X-ray and multiwavelength emission properties are analyzed futher and discussed in Paper II.

## 1. Introduction

Understanding the structure, formation and evolution of galaxies is one of the main themes of present-day astrophysics. This quest is made difficult by the complexity of galaxies, their interactions with their environment, and our limited knowledge of their observational characteristics (see Gallagher & Fabbiano 1990). While most of the studies of galaxies make use of individual energy bands, chiefly the optical, but also the radio, and more recently the X-ray and infrared (IR), it is rarer to find work comparing data from two or more emission windows. Yet, when this is done interesting insights may follow. For example, the comparison of H-band and B-band photometry led to the discovery of the well known color-magnitude relation for spiral galaxies (Aaronson, Huchra & Mould 1979; Tully, Mould & Aaronson 1982), a non-linear correlation between $L_B$ and $L_H$. The comparison of IRAS far-IR and radio continuum data led to the discovery of the well-known strong correlation and to the convincing association of the radio continuum emission with the star-forming stellar population (Dickey & Salpeter 1984; Helou, Soifer & Rowan-Robinson 1985; de Jong et al.1985); comparison of CO, H$\alpha$ and IR data led to constraints on star formation efficiencies in spirals (e. g. Young 1990); comparison of multiwavelength data, including X-rays, in late-type spirals suggested the prevalence of intrinsically obscured compact star-forming regions in higher luminosity galaxies (Fabbiano, Gioia & Trinchieri 1988; Trinchieri, Fabbiano & Bandiera, 1989).

In this paper we report the statistical analysis of the sample of 234 'normal' spiral and irregular galaxies observed in X-rays with the *Einstein Observatory* (Giacconi et al.1979), as reported in 'An X-ray Catalog and Atlas of Galaxies' by Fabbiano, Kim & Trinchieri 1992 (FKT hereafter). The present works complements the papers on the statistical analysis of the 148 E and S0 galaxies from FKT (Eskridge, Fabbiano & Kim 1995a, b, c) and completes the statistical analysis of the FKT sample. Previous exploratory work on spiral and irregular galaxies (Fabbiano & Trinchieri 1985; Fabbiano, Gioia & Trinchieri 1988, see Fabbiano 1990), was based on a much smaller sample of 51 galaxies. For the purpose of the present work, we have augmented the data presented in FKT (X-ray and optical), with H-band, mid and far-IR (IRAS), and 6cm radio continuum magnitudes and flux densities from the literature. This gives us representative coverage over the entire electromagnetic emission spectrum of spiral galaxies, and allows us to explore the full range of emission processes and the interaction of different galaxian emission components. These phenomena include direct or reprocessed stellar emission (optical and IR); emission from the evolved component of the stellar population, hot ISM, and nuclei (X-rays); synchrotron emission of cosmic-ray electrons interacting with the galaxian magnetic fields, and thermal emission of $\sim 10^4$K hot ISM (radio continuum). These different emission bands have different sensitivities to absorption, and their comparison may also give us some insight on the dust content of the emitting regions (e.g.Palumbo et al.1985; Fabbiano & Trinchieri 1987).

The size of the FKT sample of spiral and irregular galaxies allows us to explore the dependence of these processes on galaxian morphology, one of the key parameter-axis in spiral galaxies (Whitmore 1984). Such a dependence was suggested by earlier work (Fabbiano & Trinchieri 1985; Fabbiano, Gioia & Trinchieri 1988), but those results were based on much smaller samples. Here we analyse separately bulge-dominant (S0/a-Sab), intermediate (Sb-Sbc), and late-type (Sc-Irr) galaxies; we then intercompare these results and we compare them with those of the entire sample.

This is the first paper of a 2-paper series. In this first paper we describe the sample and the data analysis; we report the results of the analysis; and we discuss the possible effects of selection biases. In the companion paper (Fabbiano & Shapley 2001; hereafter Paper II) we look in detail at the astrophysical significance of the results, and we compare our results with those of other related work.

## 2. The Sample

The sample used for the statistical analysis consists of 234 spiral and irregular galaxies belonging to the FKT sample (Fabbiano et al.1992). As described in FKT, it consists of relatively nearby galaxies, all observed with *Einstein*. This was the first sample of galaxies ever to be observed in X-rays, and was mostly assembled to be a representative (optically selected) sample of normal galaxies, spanning the full range of morphologies and luminosities. To reduce selection biases, FKT used the RSA (Sandage & Tammann 1987) and RC2 (de Vaucouleurs, de Vaucouleurs & Corwin 1976) as basic selection catalogs, by adding to the sample all RSA/RC2 galaxies present in the regions of the sky observed with *Einstein* included in the catalog. Fig. 1 shows the histogram of absolute magnitudes of our sample. It compares well with the corresponding histogram from the RSA.

The FKT sample includes galaxies of all morphological types. Fig. 2 shows the distribution of morphologies in the spiral sample. All types from S0/a ($T = 0$) to Irr ($T = 10$) are represented. For the purpose of our analysis, besides considering the entire sample of 234 spiral and irregular galaxies, we also divided the sample into three morphological subsamples:the 'early' sample, $T = 0 - 2$ (58 S0/a-Sab, and 7 Amorphous); the 'intermediate' sample, $T = 3 - 4$ (Sb-Sbc, 62 galaxies); and the 'late' sample $T = 5 - 10$ (Sc-Irr, 107 galaxies). Since the early sample in this definition would include 7 Amorphous galaxies (see §3.), we further excluded these galaxies. So defined, these subsamples are representative of bulge-dominant systems, bulge/disk systems, and disk/arm-dominant systems respectively. Dividing the sample according to morphology is motivated by earlier results which have suggested that the multiwavelength statistical properties of spiral galaxies are morphology-dependent (Fabbiano & Trinchieri 1985; Fabbiano, Gioia & Trinchieri 1988).

The FKT spiral sample includes a number of AGN. Twenty of these are X-ray-bright powerful Seyfert galaxies and were identified as such in FKT. The nuclear X-ray source in these galaxies totally dominates the X-ray emission, which is then the expression of the AGN and cannot give us any useful indication on the general 'normal' X-ray emitting population. We have excluded galaxies flagged as AGN by FKT from our analysis, but they are included in some of the figures. However, more recent work with more sensitive data has revealed that nuclear activity, once thought to be an extraordinary phenomenon, is instead rather ubiquitous, albeit at a very low level (Ho, Filippenko & Sargent 1997). The separation of AGN from 'normal' galaxies becomes then a philosophical issue in the case of low luminosity activity. Since most bulge galaxies may host nuclear massive black holes ( e.g. Magorrian et al 1998), undetected nuclear activity is alway possible. We have retained in our working sample 51 galaxies found by Ho, Filippenko & Sargent 1997 to have some indication of nuclear activity in their optical spectra. These include 19 low-luminosity Seyfert nuclei, as well as LINERs and nuclei with spectra intermediate between HII regions and LINERs (transition objects). Typically their nuclear X-ray sources, based on the cases where high enough resolution is available (e.g., FKT), is just one of several identifiable components in the (0.2-4) keV *Einstein* band. More recent ROSAT observations (with 5" resolution) of face-on spiral galaxies show that near-nuclear relatively bright ($L_X \sim 10^{37-40}$ergs/s) sources are rather common, but their nature is not clear: they may be low-luminosity AGN or bright black hole binaries, or bright young SNR (Colbert & Mushotzky 1999). Therefore, we do not find it justifiable to single out these galaxies. However, there may be energy bands where these faint nuclei may dominate, and this is discussed in Paper II.

The FKT sample is neither X-ray selected, nor statistically complete: it is not volume or flux limited. Therefore it cannot be used to derive X-ray luminosity functions of spiral galaxies. However, as long as the sample is representative of the range of morphological types, and covers a fair range of galaxy luminosities, it can be used for studying the relations among different emission bands in galaxies. To check for possible peculiarities, it is important to compare our results with analogous results from independent studies, using different 'representative' samples chosen for different purposes with different criteria. Discrepancies may indicate that one of these samples may not be indeed representative of the population that it purposes to study (that of spiral and irregular galaxies), and may indeed suffer from peculiar selection biases. For this type of comparison it is particularly important to look at the overall multi-wavelength spectrum of correlations, and see if we retrieve some of the well known (non X-ray) results that have been found from separate, independent studies. This type of comparison is pursued here and is discussed in greater detail in Paper II. We show there that our results are in agreement with well known IR-optical-radio relationships in spirals, and that therefore ours is a fair sample for this type of study.

## 3. The Data

Table 1 lists the galaxies (including the AGN, which are flagged) ; their coordinates; morphological types ($T$); distances; X-ray fluxes; optical($B$) and near-IR ($H$) magnitudes; *IRAS* and radio continuum flux densities; and gives the sources for the entries. In the case of non-detections, $3\sigma$ upper limits are given. Notes and references to Table 1 are given in Table 2: items 1-5 refer to FKT and other X-ray references; items 6-17 are references and notes on the infrared data; items 18-44 refer to the radio continuum data; items 45-68 refer to the H-band data. Additional information on the H-band data is given in Table 3. The variables used for the statistical analysis consist of the logs of the luminosities calculated from Table 1, and are listed in Table 4.

Details on Table 1 and on the derivation of Table 4 entries follow:

Type ($T$). The galaxies in our sample range in morphological type from $T = 0$ to $T = 10$, corresponding to Hubble types from S0/a to Irr, as listed in FKT. The sample also includes 7 T=0 galaxies with irregular morphology. These are indicated by an 'A' (Amorphous; Sandage & Tammann 1987) in the T column.

Distance (D). We have performed a thorough literature search for distance information for our sample. Thus the distances in Table 1 differ from those in FKT, which were derived from Tully (1988) for $H_0 = 50\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$. Details are given in Appendix A.1.

X-ray flux ($f_X$). X-ray data (0.2 - 4.0 keV fluxes or $3\sigma$ upper limits) were taken from FKT.

Optical magnitudes (B). Optical, extinction and inclination corrected, ($B$-band) magnitudes are from the *Third Reference Catalogue of Bright Galaxies* (RC3; de Vaucouleurs et al.1991 ). They were converted to fluxes in the B band, following Allen 1973: $f_B = 10^{-0.4\times B-8.17} \times 990$.

Near-infrared 1.65 $\mu$m magnitudes (H). To obtain near-infrared ($H$-band, 1.65 $\mu$m) data for as many galaxies in the sample as possible, we looked in the *Catalogue of Visual and Infrared Photometry of Galaxies from* $0.5\mu m$ *to* $10\mu m$ (de Vaucouleurs & Longo 1988), which contains near-infrared measurements of galaxies and references from the literature from 1961 - 1985. We found photometry data for 159 *Einstein* galaxies, (140 normal, and 19 flagged as AGN) from the references listed in the *Catalogue*.

The $H$-band data were collected from a number of different sources in the literature, and therefore the idiosyncracies of the various sources of data needed to be reconciled. First, different aperture-to-diameter ratios were used for various galaxy measurements–i.e. a smaller aperture-to-diameter ratio samples a smaller fraction of the galaxies total near-infrared magnitude. Also, several near-infrared filter systems are represented by the full set of $H$ measurements. These systems have slightly different zero-points for the conversion from magnitudes to fluxes and slightly different central wavelength and bandwidths. Since the differences in aperture-to-diameter ratio and filter system cause systematic offsets among the near-infrared data and tend to increase the scatter in correlations, the data must be corrected before it can be used for statistical analysis.

To correct the data to a consistent aperture system, we turned to the work of Tormen and Burstein 1995. In an effort to recalibrate the near-infrared Tully-Fisher relationship, Tormen and Burstein normalize a dataset of $H$-band aperture magnitudes from 1731 galaxies collected over a ten year period by Aaronson and collaborators. The central problem of homogenizing the datasets consists of correcting the $H$-band magnitudes to the same aperture/diameter ratio, such that $log(A/D) = -0.5$. In order to perform this correction, Tormen and Burstein determine empirical curves of growth for four different morphological subgroups, and use the morphologically appropriate curve of growth to correct the aperture photometry of each galaxy to the fiducial value of $H_{-0.5}$ (which is the value of $H$ evaluated at $log(A/D) = -0.5$). We found corrected $H$-band magnitudes for 87 *Einstein* galaxies in Tormen and Burstein, and adopted these magnitudes as the normalized near-infrared magnitudes.

Additionally, there were 72 *Einstein* galaxies for which we found $H$-band data in the *Catalogue of Near-Infrared and Visual Photometry*, but which are not included in the Tormen and Burstein sample. To correct the $H$-band magnitude for these 72 galaxies in a manner consistent with that of Tormen and Burstein, we found the isophotal diameter of each galaxy in the RC3 (corrected for galactic extinction in the same way that Tormen and Burstein correct the diameter); we then computed its $log(A/D)$ value based on the RC3 isophotal diameter and the aperture listed in the literature for the $H$-band measurement; finally, we applied one of the four Tormen and Burstein growth curves, based on our determination of the galaxy's morphological type, to correct the listed aperture measurement to the fiducial aperture magnitude for $log(A/D) = -0.5$–i.e. $H_{-0.5}$.

In order to check the validity of our method for correcting the magnitudes of these 72 galaxies, we also applied the method to the 87 galaxies included in the Tormen and Burstein paper, for which we also have uncorrected aperture photometry from the literature. We wanted to ascertain that our application of the Tormen and Burstein growth curves gave us corrected values consistent with the values Tormen and Burstein determined. Indeed, we found very good agreement between the corrected $H_{-0.5}$ magnitudes we calculated and the values listed in Tormen and Burstein (fig. 3).

We also addressed the issue of Galactic extinction. Tormen and Burstein correct all growth curve-corrected magnitudes for galactic extinction, using the correction $A_H = 0.1 * A_g$, which usually results in a correction of less than 0.05 magnitudes. Therefore, the 87 galaxies in our sample which were also in the sample considered by Tormen and Burstein have H-band magnitudes which are corrected for galactic extinction. We then considered the 72 galaxies in our H-band sample which were not included in the Tormen and Burstein paper. Since H-band magnitudes for these galaxies were assembled from a variety of sources in the literature, it was necessary to check whether or not each literature source included a correction for galactic extinction. We found that for all but two galaxies, the H-band magnitude in the literature was either corrected for galactic extinction, or uncorrected but with a required correction of less than 0.05 magnitudes. Therefore, we only added our own corrections to the two galaxies which did not meet the above stated criteria, IC 342, which required an H-band correction of 0.30 magnitudes, and NGC 6951, whose required correction was 0.09 magnitudes. We did not apply the negative internal extinction correction, discussed by Willick et al 1996, as it is clear that this correction is neither significant nor perhaps even valid in most cases (see the last paragraph, p. 488 of the Willick paper, where they say that they can't rule out $C^H_{int} = 0$ for Aaronson's H-band data.) The correction is: $H_{corrected} = H - C^H_{int}$*log(axial ratio) so that if $C^H_{int} = 0$, the internal extinction correction is 0.

Once we corrected all of the $H$ magnitudes to $log(A/D) = -0.5$, and had taken into account Galactic extinction, we then converted each corrected magnitude to an H-flux ($\nu F_\nu$) (units are ergs sec$^{-1}$ cm$^{-2}$), according to the specific photometric system used in the reference from which we obtain the measurement. This conversion requires the $\lambda_{eff}$, the effective central wavelength of the $H$ filter used, as well as $F_\nu(0)$, the $F_\nu$ corresponding to $H = 0.0$ mag. Therefore, the conversion to H-flux consists of the following:

$$F = \frac{c}{\lambda_{eff}} \times F_\nu(0) \times 10^{\frac{-H}{2.5}} \tag{1}$$

where $F$ is the H-flux and $c = 3 \times 10^{10}$ cm sec$^{-1}$ is the speed of light.

Table 3 lists the many conversion systems we used, and the references to which they apply. The reference numbers refer to the system of Table 2.

*IRAS* flux densities ($f_{\nu(12)}, f_{\nu(25)}, f_{\nu(60)}, f_{\nu(100)}$). The *IRAS* flux densities or $3\sigma$ upper limits were assembled from several sources (see Refs. and Table 2). For nearby extended galaxies, we adopted the values reported in Rice et al. (1988). We obtained 12, 25, and 60 $\mu$m fluxes for 238 galaxies(218 normal, 20 AGN), and 100 $\mu$m fluxes for 237 galaxies (217 normal, 20 AGN). To derive fluxes from the flux densities, the *IRAS* data were multiplied by the appropriate bandwidths and normalizations, indicated in the *IRAS Explanatory Supplement* (Beichman & Neugebauer 1984). To calculate the far-infrared flux $F_{FIR}$, we followed Lonsdale Persson & Helou 1987.

6 cm radio continuum ($f_{6cm}$). Our literature search yielded 153 flux densities and upper limits (136 for normal galaxies, and 17 for AGN). We multiplied the radio measurements by a 1% bandwidth (50 MHz), to convert flux densities to fluxes. Previous work on spiral galaxies established the connection between the non-thermal radio continuum emission of spiral galaxies and star formation (Fabbiano, Gioia & Trinchieri 1988; Dickey & Salpeter 1984; Helou, Soifer & Rowan-Robinson 1985; de Jong et al.1985), making use of 20cm flux densities, which are likely to be less contaminated by thermal emission (see Gioia, Gregorini & Klein 1982), and therefore are more representative of the nonthermal continuum. The present use of 6cm flux densities was motivated by our desire to compare the properties of early-type bulge-dominated spirals with those of E and S0s (Eskridge, Fabbiano & Kim

1995a). Although the 6cm flux cannot be used to prove cleanly the connection betweem cosmic ray production and star formation, this connection has already been proved (see refs. above). Any general consideration about connections of the overal radio emission and other galaxian properties will still be valid.

## 4. Distributions of $L_X$ and $L_X/L_B$

Figs. 4 and 5 show the distributions of X-ray luminosities $L_X$ and X-ray-to-optical ratios $L_X/L_B$ (bright AGN excluded) for the total sample, the three subsamples, and E and S0 galaxies (from FKT, Eskridge, Fabbiano & Kim 1995a) for comparison. We see the already noticed effect (e.g. Fabbiano 1990) that the distributions of $L_X$ and $L_X/L_B$ of E and S0 galaxies extend to higher values than do those of spirals. We do not see any major differences in comparing the three spiral subsamples, with the exception that the luminosity distribution of $T = 3-4$ galaxies does not include any detections in the lower luminosity bins which are populated in the other subsamples. However, the distribution of $T = 3-4$ limits is consistent with the presence of less X-ray luminous galaxies.

## 5. Correlations

Fig. 6 displays the scatter diagrams from the fifteen pairs of luminosity variables under consideration. Several features of these plots are apparent without any formal statistical analysis. First, in the plots which feature $L_X$ as the dependent variable, the flagged AGN lie clearly above the distribution of normal spiral galaxies in the vertical direction, indicating the excess nuclear X-ray emission from these objects. Second, most of the pair-wise relationships display more scatter in the early-type ($T = 0-2$, S0/a-Sab) subsample. The 7 Amorphous galaxies in the early subsample are indicated by different symbols in the scatter diagrams. They were not included in the analysis of this sample. Third, for the majority of the luminosity-luminosity pairs, the distribution of points in the middle ($T = 3-4$) morphological range is basically coincident with the upper right-hand portion of the distribution of late-type ($T = 5-10$) points.

Fig. 7 displays scatter plots for luminosity-ratio pairs. Also here we find that trends are visible in total and late/intermediate samples, but tend to disappear in the early sample.

We performed bivariate correlation tests and regression analysis as well as multivariate analysis on these data. All information (both detections and limits) was used in the analysis, by applying survival analysis techniques. Bivariate analysis was conducted with ASURV

Rev 1.1 (LaValley, Isobe & Feigelson 1992 and refs. therein), a software package that implements methods of univariate and bivariate survival analysis (both correlation tests and regression methods). We tested for the significance of each correlation, and we derived regression parameters for each of them. Multivariate analysis addresses the question: is a given correlation intrinsically significant (and thus indicative of an astrophysical effect), or is it the secondary effect of other more fundamental links? To test for the presence of intrinsic correlation among two variables, that would be present even if all other variables did not vary, we used the Spearman partial rank method (Kendall & Stuart 1976; see Fabbiano, Gioia & Trinchieri 1988, Eskridge, Fabbiano & Kim 1995a for previous applications). The partial rank analysis takes full advantage of the multi-wavelength nature of our set of data and correlations, providing information that a simple bivariate correlation analysis cannot supply. We used the generalized Spearman's rho method from ASURV to generate correlation coefficients to use in the Partial Rank analysis.

These methods and the results of the analysis are described in §6. and §7. Below we discuss biases that may affect correlation studies and show that our results are free from serious effects.

Distance biases (chiefly the Malmquist bias) are a well known danger in any correlation analysis, and may result in spurious luminosity correlations when working with flux limited samples. Our results directly confirm that a Malmquist bias is not significant. First, most regression bisector slopes (see fig. 6 and §6.) indicate non-linear relationships between variables. If the correlations were due to a Malmquist bias, they would only appear as linear relationships in the $\log-\log$ plane (power-law $\alpha = 1$). Second, even for linear correlations, a correlation is evident in flux-flux plots (not shown).

Moreover, the characteristics of our sample selection, and the inclusion of limits in the analysis, protect us from these effects. The *Einstein* sample of spiral galaxies contains an optical selection criterion, but is not defined by any *a priori* X-ray flux or volume limit, and by including upper limits in our analysis in the X-rays and in the other wave-bands, we have avoided the problem of an *a posteriori* flux-bias towards higher-luminosity objects in the various luminosity parameters. Censored analysis tools make full use of *both detections and limits*. Under these circumstances, working with fluxes may provide erroneous results, which are absent when luminosities are used. (as rigorously demonstrated by Feigelson & Berg 1983, see Fabbiano & Trinchieri 1985, Fabbiano, Gioia & Trinchieri 1988). Furthermore, we have used the Partial Spearman Rank test, to directly test if a given correlation could have arisen solely from a distance effect, by including the distance among the variables tested (§7. and Appendix A.3). All the bivariate correlations are still very significant when the correlation is tested under the hypothesis that the distance be held fixed, and the results of the multivariate analysis are only minimally affected.

Fig. 8 supports our conclusion that the sample is not affected by a distance-limited issue: we have a fair sampling of both detections and limits at any given distance.

Correlations cannot be created by a distance bias in our sample; however, the presence of upper limits could in some cases imply that we are not in the presence of a very tight functional relation, but of a 'wedge' effect. Although this possibility cannot be completely discounted, it would not change the results of the presence of correlations, it may only weaken any model based on intrinsic underlying power-laws.

Another distance-related problem consists of the uncertainty in the adopted distance for any individual galaxy. Our results are robust to uncertainties in the assumed distances. We obtain very consistent results when we use directly the set of distances in FKT, or the present set of Table 1. The FKT distances are mostly from Tully 1988, corrected for an $H_o = 50$. Some of these distances give values for nearby galaxies (e.g. M82), which differ significantly from recent Cepheid-based estimates. However, these differences do not affect the results of the correlation analysis. Moreover, we tested the robustness of our results by randomly perturbing each adopted galaxy distance by either a factor of two high or low. This is the outer envelop in the dispersion from a comparison of distances from galaxian indicators and distances from the Hubble flow that we have assembled here (Appendix 1). Even in this extreme case, the basic correlation slopes stand. Uncertainties arising from different Hubble flow corrections are much smaller (see Appendix 1, where we compare YTS and CMB corrections). Comparing runs of our bivariate probability and regression analyses for the entire set of correlations using the two set of distances shows that in all cases the resulting effects on the correlations are insignificant (well within the errors). The reason is that the cosmic scatter of galaxian properties at a given luminosity is much greater than the scatter introduced by current distance uncertainties.

Another possible bias consists of beam-size effects, which could turn a linear power-law relation between two variables into a non-linear relation, if one of the variables is observed with a small beam. This effect occurs if the galaxies further away are systematically more luminous, of course of smaller angular size, and therefore not so undersampled by a small beam-size as a nearby galaxy would be. A beam-size effect could also obscure the strength of an observed correlation, by introducing extra scatter into a distribution of points, because the small beam samples a different fraction of the total galaxy luminosity based on the angular size of the galaxy.

Beam-size effects should not be a problem with the X-ray flux data, since the *Einstein* field is much larger than any of the galaxies observed, and a method akin to surface photometry was followed to derive the fluxes, while limits were derived from areas comparable to the optical extent of the galaxies (see FKT). Beam-size effects are also not a problem for optical ($B$) and near-IR ($H$) data, since in both cases the magnitudes refer to the same fraction of the total galaxy. We addressed the finite nature of the *IRAS* beam-size by using Rice et al.1988 fluxes, computed specially for large optical galaxies. To investigate possible beam size dependencies in the 6$cm$ data we have plotted galaxies of different optical sizes with different symbols in a $L_X - L_{6cm}$ scatter plot (fig. 9). We do not find any significant differences that may be linked to the galaxy size and conclude that the 6cm data do not suffer significantly of beam size bias.

Because of the finite resolution of the observations, expecially in the infrared and X-ray bands, in a very few cases of close-by or interacting galaxies the fluxes may include the contribution of more than one object. Table 2 shows that, of the galaxies used for the analysis, no 'early' sample galaxy is thus affected, and only 1 (out of 62) 'intermediate' sample galaxy, and 7 (out of 107) 'late' sample galaxies suffer of source confusion in the IR; given the uneven data coverage, only 3 of these latter galaxies were included in the multivariate analysis. Inspection of FKT shows that confusion in the X-rays is also likely. Given the small percentage of the sample suffering of this problem, we do not think that our results would be significantly affected. This effect may result in some scatter in the correlations, which are however expecially tight in the 'late' sample. The only foreseeable effect would be to worsen somewhat correlations involving the IR or the X-ray band and one of the other variables. However, the resulting scatter would be well within the observed dispersion of the correlations.

Finally, we checked that uncertainties in the $H_{0.5}$ magnitude corrections (§3.) did not affect our results, by rerunning the analysis for a set of $H_{0.5}$ values we calculated using Tormen & Burstein (1995) prescription (see fig. 3), and comparing the results with those obtained from the values in Table 1. The results are virtually identical.

## 6. Bivariate Analysis

We report below the results of bivariate correlation tests and regression analysis for each of 15 luminosity pairs in the matrix of combinations among the six variables $L_X$, $L_B$, $L_H$, $L_{12}$, $L_{FIR}$, and $L_{6cm}$. After applying the same tests to correlations including each of the IR variables ($L_{12}$, $L_{25}$, $L_{60}$, and $L_{100}$) we concluded that 12 and 25 $\mu$m behave similarly and so we adopted $L_{12}$ as representative of the mid-IR emission; the same is true for $L_{60}$, and $L_{100}$ and $L_{FIR}$ (which is a combination of the two). In addition, we report the results of correlation tests applied to the X-ray-optical ratio, $L_X/L_B$ and five other luminosity ratios:

$L_{60}/L_B$, $L_{6cm}/L_B$, $L_{12}/L_B$, $L_{60}/L_{100}$, and $L_H/L_B$.

The bivariate package, BIVAR, in ASURV provides three methods for testing for the presence of a correlation between two variables containing censored data points: the Cox hazard model, the generalized Kendall's tau, and the Spearman's rho. Cox's hazard, a parametric method –i.e. one that requires certain assumptions with respect to the underlying distribution of the sampled data points– can only be used when there is one type of censoring (upper or lower limits), and when the censoring only occurs in the dependent variable. The other two methods, Kendall's tau and Spearman's rho, are non-parametric tests, operating on the basis of the sample values alone, without any assumptions regarding the underlying population. Both of the non-parametric tests can handle censoring in both the independent and dependent variable. Since many of the luminosity pairs under consideration contained upper limits in both variables, we could not apply the Cox method to these cases, and simply used the Kendall and Spearman correlation tests. Wherever applicable, the Cox methods gives results – not shown – consistent with those of the other two methods.

Table 5 displays the results of the bivariate luminosity correlation tests for the total ($T = 0 - 10$), early ($T = 0 - 2$), intermediate ($T = 3 - 4$), and late ($T = 5 - 10$) samples. For each test pair and sample, are listed: the number of data points ($N_{tot}$); the number of upper limits ($N_{lim}$), in the order: limits on the first variable of the pair, limits on the second variable, and limits on both variables; the Kendall test statistic ($\tau_K$), and corresponding probability of the correlation arizing by chance ($P_K$); the Spearman's correlation coefficient ($r_{SR}$), and corresponding probability ($P_{SR}$).

All 15 pairs of luminosities are highly correlated in the total sample. All of the correlations are characterized by the probability $P \leq 10^{-6}$ that the null hypothesis of no correlation is true, except for the pair $(L_{6cm}, L_H)$, which has a weaker correlation.

However, the results differ when we compare the 3 morphological subsamples:

- In the early ($T = 0 - 2$, S0/a-Sab) sample, the correlations among $L_{12}, L_{FIR}, L_{6cm}$ are all very significant ($P \leq 10^{-6}$). Similarly strong are the correlations of $L_B$ with $L_X$ and $L_H$, while the $(L_X, L_H)$ one is marginal. Typically, correlations among one of $L_{12}, L_{FIR}, L_{6cm}$ with either $L_B, L_X, L_H$ are poor or absent.

- In the intermediate ($T = 3 - 4$, Sb-Sbc) sample, strong correlations persist among $L_{12}, L_{FIR}$, and $L_{6cm}$ and between $L_B$ and $L_H$; $L_X$ is more strongly correlated with the IR than with either $L_B$ or $L_H$. $L_H$ is now significantly correlated with both $L_{12}$ and $L_{FIR}$.

- In the late ($T = 5 - 10$, Sc-Irr) sample, all the pairs of variables are very strongly correlated, with $P \leq 10^{-6}$.

Table 6 displays the results of the bivariate luminosity-ratio correlation tests for the total, early, intermediate, and late samples. The format is the same as for Table 5. As is the case for the luminosity correlations discussed above, we find morphology related differences. In the total sample we find that X-ray brighter galaxies (for a given optical luminosity) are those brighter in the radio continuum, mid and far-IR, and with warmer far-IR colors. However, these color correlations only arise in the intermediate and late samples, and are absent in the bulge-dominated early sample. As discussed in Paper II, these effects may all be related to star-formation activity. They also reflect the existence of non-linear power-law relations between the luminosities (see below).

Linear regression analysis was applied to bivariate correlations to estimate the functional relations between the variables. ASURV's BIVAR offers three routines for linear regression analysis of censored data: EM (estimation-maximization) method, Buckley-James method, and the Schmitt's binning method (Schmitt 1985). The first two methods only handle data sets which possess censoring in the dependent variable alone. Schmitt's method, however, addresses the problem of censoring in both variables. Thus, for many of the luminosity pairs with censoring in both variables, we were able to apply only Schmitt's method to perform regression analysis. We note, however, that we found very good agreement among the three regression methods for the luminosity pairs with censoring such that we were able to apply all three. Instead of defining one variable as "independent" and the other as "dependent," for each luminosity pair, $(X, Y)$, in each morphological subgroup, we obtained the Schmitt's method regression coefficients (slope, intercept, and the uncertainties in these quantities) for both $(X|Y)$ and $(Y|X)$. We then used the bisector of these regressions as our final estimate of the linear relationship between the variables (Isobe et al.1990). Appendix A.2 discusses the derivation of these bisectors. We did not apply this same analysis to the luminosity-ratios, because, while the luminosity-ratio pairs display signals of gross correlation, there is a lot more scatter present in these correlations than in the correlations between luminosities, inducing a large uncertainty into any obtained value of regression slope.

The power-law dependencies of the bivariate correlations between each pair of luminosities are given by the slopes of the regression bisectors which are tabulated in Table 7, together with an estimate of their uncertainty ($\sigma_S$), and the intercepts ($Int.$) of the bisectors. These bisector lines, along with the regression lines are plotted on the scatter diagrams of fig. 6. Inspection of the regression bisectors reveals, first, that different luminosity pairs are described by different power-law relationships; second, that the power-law relationship for a given luminosity pair may be a function of morphological type.

In the total sample, the regression bisectors for the correlations between X-ray, H, far-IR, and radio countinuum luminosities are consistent (within $2\sigma$) with linear relations, i. e. all these luminosities increase in parallel. Other correlations are definitely non-linear. These include among others the well known $L_B \propto L_H^{0.7}$ relation (Aaronson, Huchra & Mould 1979), and the strong linear FIR / radio-continuum correlation (Dickey & Salpeter 1984; Helou, Soifer & Rowan-Robinson 1985; de Jong et al.1985). These results are in agreeement with previous studies of large different representative samples of spiral galaxies, and reinforce our conclusion of §2. that our sample is representative of the spiral galaxy population. In disagreement with previous reports, we find $L_X \propto L_B^{1.5}$, steeper than the relation reported between these two quantities in Fabbiano, Gioia & Trinchieri 1988, which however was based on the analysis of a much smaller sample of 51 galaxies. We will discuss the implications of this result in Paper II. We suggest there that different mechanism may be responsible for these effects in early and late-type spirals: hot halos in bulge-dominated galaxies, and obscuration effects in disk-dominated galaxies and irregulars.

Table 7 shows some morphology-related changes in the relation slopes. The best-defined bisectors are in the late sample, where all of the correlations are very significant. The results of the regression analysis include regression bisectors that are consistent with a power-law exponent $\alpha \approx 1$ for the following luminosity pairs: $(L_X, L_{FIR})$, $(L_{FIR}, L_{6cm})$, $(L_X, L_{6cm})$, $(L_{6cm}, L_{12})$, and $(L_X, L_H)$. $(L_{6cm}, L_H)$ could also be consistent with a linear trend, but the error is significantly larger for this correlation. The other pairs exhibit relationships with power-laws significantly different from unity. These relationships and their possible implications are discussed in Paper II. We conclude there that the linear relations are likely to result from the overall connection of those emission bands to star-formation related phenomena. The non-linear relations point to other effects, including extinction and possibly the characteristics of the star formation history.

For certain pairs of luminosities, the distribution of early- and intermediate-type galaxies spans a smaller range in luminosity (typically restricted to higher luminosities), than does the distribution of late-type galaxies. To derive correlation and regression coefficients, we simply used all the available data, for each morphological subsample, regardless of luminosity range. This approach leads to the question of whether the differences in regression slope which we found for different morphological samples [e.g. in the $(L_{FIR}, L_{12})$ correlation] may be only an artifact of the different ranges in luminosity which the different samples span. In Paper II we address explicitly this questions in the cases where the results may be affected, by analyzing the data in restricted luminosity ranges.

## 7. Multivariate Analysis

We applied the Partial Spearman Rank analysis to all of the groups of three, four, five, and six variables which can be formed from $L_X$, $L_B$, $L_H$, $L_{12}$, $L_{FIR}$, and $L_{6cm}$. We also held explicitly fixed the distance (D), to verify that our results are not affected by a distance bias.

The samples used for the multivariate analysis are smaller than those used to conduct bivariate correlations and regressions, because we were restricted to include only those galaxies with data for all six variables. The results for the six variable tests are given in Table 8. Results for smaller groupings of variables are tabulated in Appendix A.3. Table 8 lists the test pair, the parameters held fixed in the test, the partial rank coefficient, Student t, and corresponding probability of chance correlation, for the total sample and each of the 3 morphological subsamples. The number of points used in each sample is also given ($N$). Note that the results for the early subsample can only be considered indicative, given the small number of points. These conclusions are supported by the analysis of Paper II, which uses the larger samples available for more limited groupings of variables.

Fig. 10 shows in a diagrammatic form the results of the Partial Rank analysis for the total, early, intermediate and late samples. Only the strongest links ($P < 2\%$) are plotted, with their relative strength indicated by the number of lines connecting variables. Two correlations remain very significant, no matter what combination of other variables we held fixed: $L_B - L_H$ and $L_{FIR} - L_{12}$. $L_B$-$L_H$ links stellar emission processes (Aaronson, Huchra & Mould 1979), and while the presence of a strong fundamental correlation is not surprising, it also points to a basic connection between the IMF of low mass and intermediate-to-high mass stars (Trinchieri, Fabbiano & Bandiera, 1989). The tight 12$\mu$m–FIR correlation is consistent with previous findings pointing to evidence of similarity in the grain size spectrum and distribution in the dense ISM of all spirals (see Helou, Ryter & Soifer 1991, Knapp, Gunn & Wynn-Williams 1992, and refs. therein). In this picture the 12$\mu$m emission would be due to small size grains heated to non-equilibrium temperature for short times by the same UV photons field responsible for the FIR emission.

We find morphology related differences in the correlations. In the early sample there is an additional strong link of $L_{6cm}$ with $L_{12}$. The intermediate sample results look similar, although the $L_B - L_H$ link is by far the strongest. The results change in the late sample: the $L_B - L_H$ link persists, but otherwise we are in the presence of strong connections of both 12$\mu$m and radio continuum with the FIR, again suggesting the dominant effect of star-formation processes in these galaxies (Paper II). Inspection of Appendix A.3 (Table 11D) shows that most combinations of variables also yield a significant X-ray – FIR link in Sc-Irr galaxies, associating the X-ray emission with the star forming population and associated processes. This point will be investigated further in Paper II.

Table 9 compares results for the case where the distance is held fixed in the analysis, and where is not considered. To explore this point further, we performed the Partial Spearman Rank test on each pair of variables (holding only the distance fixed), by using the same sample sizes used in the bivariate analysis. The results (not shown) compare well with those of Table 5.

While we have $X$ and $B$ data for all of the galaxies and far-IR data for 93% of the sample, our coverage is much sparser in the $H$ and 6cm bands. The regression analysis of each luminosity pair was performed for galaxy samples with data in both of the variables in the luminosity pair, regardless of coverage in the other four variables, for the purpose of using the largest sample possible for each pair. Instead, for the multivariate Spearman partial rank analysis, which requires data for each galaxy in all six of the variables under consideration, the sample becomes reduced to those galaxies observed in all of the parameters: $X, B, H, 12\mu m, FIR$, and $6cm$, numbering 94 galaxies. To explore the effects of the two different sample selections, we performed a partial rank analysis on subsamples of variables, by using the largest number of objects possible in each case. After checking against the results for the 94 galaxies (6-variable) sample, we find that our conclusions are generally not affected: while some correlations are more significant in the larger samples, the relative strenghts of the different correlations – which is what we want to establish with the multivariate analysis – follow similar patterns.

## 8. Summary and Conclusions

We have performed bivariate and multivariate survival analyses, which keep into account censoring (limits), on a sample of 234 galaxies, covering morphological types from S0/a to Irregular. These galaxies were all observed in X-rays with the *Einstein Observatory* (FKT) and their X-ray emission is not likely to be dominated by an AGN, although some of them may harbor a faint active nucleus (i.e. they are representative of normal galaxies in X-rays). Besides the X-ray emission, included in the analysis were optical (B), near-IR (H), mid- and far-IR, and radio continuum emissions. Their morphological type was considered explicitly in the analysis by dividing the sample in 'early' (S0/a-Sab, bulge dominated), 'intermediate' (Sb-Sbc), and 'late' (Sc-Irr) subsamples.

In this paper, we have described the sample and the derivation of the variables used in the analysis; we have reported in details the results of the statistical analysis; and we have discussed possible biases, to conclude that our overall results are not likely to be affected in any major way, by either distance bias, incomplete data coverage, and beam-size effects.

We find that most pairs of luminosities are correlated when considered individually. A regression analysis demonstrates that different correlations follow different power-law relations. Some of these power-laws are morphology dependent. These effects and their significance are discussed further in Paper II.

When we ask which of these correlations are likely to be fundamental, and which instead may arise from secondary effects, we find that only two are consistently very strong, regardless of galaxy morphology. These are the $L_B - L_H$ and the $L_{12} - L_{FIR}$ correlations. The former links stellar emission processes Aaronson, Huchra & Mould 1979), and points to a basic connection between the IMF of low-mass and intermediate-to-high-mass stars (e.g. Trinchieri, Fabbiano & Bandiera, 1989). The latter may be related to the heating of small and larger size dust grains by the same UV photon field (e.g. Helou, Ryter & Soifer 1991).

Other highly significant 'fundamental' correlations exist, but are morphology-dependent. In particular, in S0/a-Sab (and also, but possibly less strikingly in Sb-Sbc) galaxies we observe a strong link of radio-continuum and 12$\mu$m (not FIR) emission, while in Sc-Irr, the strong link is with FIR (not 12$\mu$m) emission. These differences we will explore further in Paper II.

We also find that in the late sample (Sc-Irr) there is an indication of an overall connection of X-ray, mid and far-IR, and radio-continuum emission, which could be related to the presence of star-forming activity in these galaxies (see also Paper II).

We thank Louis Ho, Jonathan Mc Dowell, and Kim McLeod for their useful input and interest in this work, which was part of the Harvard undergraduate senior thesis of A. Shapley. We thank John Huchra for discussions on galaxy distances. We used the NASA Extragalactic Database (NED) to gather some of the data used in this paper. The ADS abstract service was of help in our literature search. This work was supported by NASA grant NAGW–2681 (LTSA), and by NASA contract NAS 8–39073 (Chandra X-ray Center).

## A. 1. Distances

For this paper we have revised the distances used in the FKT catalog. The motivation was that recent accurate direct measurements from local indicators exist for nearby galaxies, which make up a large fraction of the sample. We have performed a thorough literature search through November 1999 to determine the most reliable, up to date distances for our sample. If a recent and reliable distance estimate was not found, we adopted $H_0$ distances for $H_0$=75 km s$^{-1}$ Mpc$^{-1}$, derived from the Yahil, Tammann & Sandage (1977; YTS hereafter) corrected velocity. Heliocentric velocities ($V_0$) were taken from NED. For each galaxy, Table 10 lists the adopted modulus and distance, followed by the heliocentric velocity, the YTS corrected velocity, and $H_0$ distances for $H_0$=75 km s$^{-1}$ Mpc$^{-1}$. For many galaxies a modulus and distance are not listed in columns 2 and 3. This is because there are no modern distance estimates available in the literature. In those cases where we give no $H_0$ distance, the actual measured distance is solid enough that there is no defensible reason for not using it.

To estimate the uncertainties that may arise from applying different corrections to the heliocentric velocities, we also estimated velocities relative to the Cosmic Microwave Background (CMB) frame, using a code provided by John Huchra (private communication). The plot of the fractional difference between YTS and CMB velocities (fig. 11) for galaxies with Hubble flow distances shows that differences are within 20% for $V > 1500$km/s and within 30% down to 1000 km/s. Seven more nearby galaxies have differences between 40% and 60%. In §5. we discuss how these uncertainties do not produce significant differences in the results of our correlation analysis.

Below, we give detailed notes and references.

Notes on groups:

The Local Group: We adopt a distance modulus of 18.50 for the LMC (Madore & Freedman 1998). While there are competing, generally shorter, distance moduli for the LMC in the recent literature (e.g. Luri et al. 1998), the range of values under discussion is small: a systematic uncertainty of ∼0.2 magnitudes in the zero-point of the distance modulus will not effect the results of this study. A distance modulus of 18.50 gives a physical distance of 50 kpc. The SMC has a distance modulus greater than that of the LMC by ∼0.4 magnitudes. Although studies differ on the zero-point of the distance scale, nearly all of them are consistent with this difference in the distances to the two Clouds (e.g. Böhm-Vitense 1997). We thus adopt an SMC distance modulus of 18.90, corresponding to a distance of 60 kpc. For our other Local Group objects, we adopt Cepheid distances tied to the adopted modulus for the LMC. For NGC 224 (M31), IC 1613, and NGC 598 (M33) we adopt the result of

Freedman & Madore (1991). For NGC 6822, we adopt the result of Gallart, Aparicio & Vílchez (1996).

The Sculptor Group: We adopt the Cepheid distance to NGC 300 from Freedman et al. (1992). We note that there is evidence of a substantial distance spread amongst Sculptor group members (Puche & Carignan 1988). We thus adopt the relative distances from Puche & Carignan (1988) between NGC 300 and our sample: $\Delta(m-M) = 0.74$ for NGC 247; $\Delta(m-M) = 0.79$ for NGC 253; $\Delta(m-M) = 1.37$ for NGC 7793. Côté et al. (1997) argue that NGC 625 is a Sculptor group member, lying between the main concentration, and NGC 45. We adopt a distance of 4.9 Mpc based on the relative velocities and distances of NGC 7793, NGC 45, and NGC 625.

The IC 342/Maffei 1 group: Krismer, Tully & Gioia (1995) derive Tully-Fisher distances to NGC 1560 and UGCA 105. The mean of these measures gives a group distance of 3.6 Mpc. The best distance estimate for NGC 1569 is that of Karachentsev et al. (1997), who derive a distance of 1.7 Mpc from bright stars. Krismer et al. (1995) find that NGC 1569 does not yield a plausible Tully-Fisher distance.

NGC 1533 & NGC 1566 (The Dorado Group): The mean velocity of 11 group members tabulated in Ferguson & Sandage (1990) is 1342 km/sec. We adopt this for both galaxies, and compute and $H_0$ distance.

NGC 2775 & NGC 2777: We use an $H_0$ distance, based on the mean velocity of the two group members.

NGC 2992 & NGC 2993: We use an $H_0$ distance, based on the mean velocity of the two group members.

The M81 group: We adopt the Freedman et al. (1994) Cepheid distance to M81, and use this distance for NGC 3034, NGC 3077, IC 2574, and NGC 4236. For NGC 2366, we adopt the Cepheid distance from Tolstoy et al. (1995). For NGC 2403, we adopt the Cepheid distance from Freedman & Madore (1988).

The Leo I group: We adopt the Cepheid distance to M96 (NGC 3368) and NGC 3489 from Kennicut et al (1998).

The CVn I cloud: We adopt recent bright-star distances for the following members of our sample: NGC 4190 from Tikhonov & Karachentsev (1998); NGC 4214 from Makarova, Karachentsev & Georgiev (1997); NGC 4244 from Karachentsev & Drozdovksy (1998).

The M101 group: Stetson et al.(1998) state: "An unweighted average of the two [Cepheid-based] moduli is 29.28 +/- 0.14 mag (with the uncertainty of the LMC modulus having been subtracted from the uncertainty each of the two estimates and added back in to the uncertainty of the average), implying a distance of 7.2 +/- 0.5 Mpc." This is for M101 (NGC 5457). We adopt this result for NGC 5204, NGC 5474, NGC 5477, and NGC 5585 also.

The Cen A group: Saha et al. (1995) derive a Cepheid distance for NGC 5253. For NGC 5236 (M83) Eastman, Schmidt & Kirshner (1996) derive a SNII expanding photosphere distance.

The NGC 3166 group: Garcia et al. (1996) derive a group-average Tully-Fisher distance of 8.8 Mpc. We adopt this for both NGC 3166 and NGC 3169.

The Ursa Minor Cluster: Pierce & Tully (1988) derive a mean Tully-Fisher distance of 15.5 Mpc for the Ursa Minor cluster. We adopt this distance for NGC 3729, NGC 3893, NGC 3896, NGC 4051, IC 749 and IC 750.

The Fornax Cluster: Shanks (1997) quotes a Cepheid distance for NGC 1365 of 18.4. We adopt this distance for NGC 1317, NGC 1350, and NGC 1386 as well. For NGC 1380, we adopt the surface brightness fluctuation (SBF) distance reported by Hamuy et al. (1996).

The Virgo Cluster: Given the evidence for substantial depth to the Virgo cluster (e.g. Yasuda, Fukugita & Okamura 1997), we adopt individual distance estimates to Virgo members as follows: For NGC 4321 (M100), we adopt the Cepheid distance from Freedman et al. (1994). For NGC 4536 we adopt the Cepheid distance from Saha et al. (1996). For NGC 4571, we adopt the bright-star distance of Pierce, McClure & Racine (1992). For NGC 4579, we adopt the SNII expanding photosphere distance from Eastman et al. (1996). For NGC 4639, we adopt the Cepheid distance from Sandage et al. (1996). Schöniger & Sofue (1997) derive distances for NGC 4303, NGC 4438, and NGC 4647, based on combined CO and H I Tully-Fisher. For NGC 4429, we adopt the fundamental plane distance of Gavazzi et al 1999. For NGC 4527 we adopt the SNIa distance from Shanks (1997). Teerikorpi et al. (1992) give Tully-Fisher distances for NGC 4567 and NGC 4845. Yasuda et al. (1997) give *B*-band Tully-Fisher distances for a large sample of Virgo galaxies. The Yasuda et al. (1997) distances match the available Cepheid distances within the errors. We adopt the Yasuda et al.(1997) distances for the following galaxies: NGC 4178, NGC 4192, NGC 4206, NGC 4212, NGC 4216, NGC 4235, NGC 4254, NGC 4298, NGC 4351, NGC 4388, NGC 4394, NGC 4424, NGC 4450, NGC 4501, NGC 4522, NGC 4535, NGC 4548, NGC 4569, NGC 4651, NGC 4654, NGC 4689, NGC 4698. We adopt the Yasuda et al. (1997) mean Virgo distance of 16.0 Mpc for NGC 4643, and NGC 4665. We adopt the Gavazzi et al.(1999) distances for NGC 4461, NGC 4464, NGC 4477, NGC 4503.

Systems behind the Virgo cluster: Yasuda et al. (1997) also report Tully-Fisher distances for the following galaxies in the background of the Virgo cluster: NGC 4224, NGC 4246, NGC 4260, NGC 4378.

The Grus Group: We adopt a mean $H_0$ distance for the group members (NGC 7496, NGC 7552, NGC 7582, NGC 7590, NGC 7599).

Notes on individual galaxies:

NGC 628 (M74): Sharina, Karachentsev & Tikhonov (1996) derive a distance based on bright stars. They find similar distances for several of M74s dwarf companions. Their result is roughly between the very discrepant results from older studies. Distance confirmed by Sohn & Davidge (1996).

NGC 672: We adopt the result of Sohn & Davidge (1996), who derive a distance for NGC 672 based on bright stars.

NGC 1313: Ryder et al. (1995) cite a mean distance of 4.5 Mpc based on tertiary distance estimators. They further state that there is no discrepancy between the long- and short-scale distance camps in the cited work.

NGC 1559: We adopt the SNII expanding photosphere distance from Eastman et al. (1996).

NGC 2441: We adopt the SNIa distance from Riess, Press & Kirshner (1996).

NGC 3351: Graham et al. 1997 quote a Cepheid-based distance modulus of $30.01+/-0.19$, corresponding to a distance of $10.05+/-0.88$ Mpc.

NGC 3368: Kennicutt et al. 1998, ApJ 498 181 quote a Cepheid-based distance modulus of $30.27+/-0.13$, corresponding to a distance of 11.3 Mpc.

NGC 3628: There are no direct distance estimates. NGC 3628 is a member of the NGC 3627 group (Garcia 1993). Theureau et al. (1997) quote a Cepheid-based distance to NGC 3627, and we adopt this distance for NGC 3628.

NGC 4258: (M106) Herrnstein et al.(1999) derive a geometric distance of 7.2 Mpc for a distance modulus of $(m-M)_0 = 29.29$.

NGC 4449: We adopt the bright-star distance from Karachentsev & Drozdovsky (1998).

NGC 4565: We adopt the result of Forbes (1996), which is based on an average of the results from the globular cluster luminosity function, SBF, and the planetary nebula luminosity function (PNLF).

NGC 4594 (M104): We adopt the SBF distance from Ajhar et al. (1997).

IC 4182: We adopt the Cepheid distance from Saha et al. (1994).

NGC 5037: There are no direct distance estimates. However Ferguson & Sandage (1990) list NGC 5037 as a member of the NGC 5044 group. deVaucouleurs & Olson (1984) give Faber-Jackson distances for two group members (NGC 5017 and NGC 5044). Tutui & Sofue give a distance for NGC 5054 based on the average of H I and CO Tully-Fisher. We adopt the mean of these distances for NGC 5037.

NGC 5194 (M51): We adopt the PNLF distance from Feldmeier, Ciardullo & Jacoby (1997).

NGC 6503: We adopt the bright-stars distance from Karachentsev & Sharina (1997).

NGC 6946: Pierce (1994) gives a Tully-Fisher distance of 5.5 Mpc. Schmidt et al. (1994) give an SNII expanding photosphere distance of 5.7 Mpc. Schöniger & Sofue (1994) give a CO Tully-Fisher distance of 5.4 Mpc. We adopt 5.5 Mpc.

NGC 7331: We adopt the Cepheid distance from Hughes et al. (1998).

Tutui & Sofue (1997) derive distances based on the average of CO and H I Tully-Fisher that we adopt for the following members of our sample: NGC 520, NGC 772, NGC 1961, NGC 4038.

Schöniger & Sofue (1994) derive distances from the average of H I and CO Tully-Fisher, that we adopt for the following members of our sample: NGC 2276, NGC 3079, NGC 4631, NGC 4736, NGC 5907, NGC 7469. IC 5283 is a companion of NGC 7469, and we adopt the same distance as NGC 7469.

We adopt distances quoted by Shanks (1997), based on Cepheids or SNIa, for the following members of our sample: NGC 2841, NGC 3351, NGC 3389. The distance to NGC 3351 is confimed by Graham et al.(1997).

We adopt SNIa and SNII distances from Pierce (1994) for the following members of our sample: NGC 3184, NGC 7339.

## A. 2. Calculation of the Regression Bisectors

The bisector slope ($\beta_{bis}$) and intercept($\alpha_{bis}$), where estimated using the following expressions from Isobe et al (1990):

$$\beta_{bis} = (\beta_1 + \beta_2)^{-1}[\beta_1\beta_2 - 1 + \sqrt{(1+\beta_1^2)(1+\beta_2^2)}] \tag{A1}$$

$$\alpha_{bis} = y_{int} - \beta_{bis}x_{int} \tag{A2}$$

where $y_{int}$ and $x_{int}$ are the coordinates of the intersection point of two the regressions, $y = \beta_1 x + \alpha_1$ and $y = \beta_2 x + \alpha_2$.

The bisector slope, $\beta_b is$ is a function of two interdependent variables, $\beta_1$ and $\beta_2$. Therefore, in order to find the uncertainty in $\beta_b is$, we need to calculate the following (from Isobe et al.1990):

$$\sigma^2_{\beta_{bis}} = \sigma^2_{\beta_1}(\frac{\partial\beta_{bis}}{\partial\beta_1})^2 + \sigma^2_{\beta_2}(\frac{\partial\beta_{bis}}{\partial\beta_2})^2 + 2\sigma_{\beta_1\beta_2}(\frac{\partial\beta_{bis}}{\partial\beta_1})(\frac{\partial\beta_{bis}}{\partial\beta_2}) \tag{A3}$$

where $\sigma_{\beta_1}$ and $\sigma_{\beta_2}$ are the uncertainties on the slopes, $\beta_1$ and $\beta_2$, respectively; $\frac{\partial\beta_{bis}}{\partial\beta_1}$ and $\frac{\partial\beta_{bis}}{\partial\beta_2}$ are the respective partial derivatives of $\beta_{bis}$ with respect to $\beta_1$ and $\beta_2$; $\sigma_{\beta_1\beta_2}$ is the covariance of $\beta_1$ and $\beta_2$.

We obtained $\sigma_{\beta_1}$ and $\sigma_{\beta_2}$ from the Schmitt's regression analysis package in ASURV, which provides a bootstrap error analysis. The expressions for the partial derivatives are:

$$\frac{\partial\beta_{bis}}{\partial\beta_1} = \frac{(1+(\beta_2)^2)\beta_{bis}}{(\beta_1+\beta_2)\sqrt{(1+\beta_1^2)(1+\beta_2^2)}} \tag{A4}$$

$$\frac{\partial\beta_{bis}}{\partial\beta_2} = \frac{(1+(\beta_1)^2)\beta_{bis}}{(\beta_1+\beta_2)\sqrt{(1+\beta_1^2)(1+\beta_2^2)}} \tag{A5}$$

According to Isobe et al.1990, $\sigma_{\beta_1\beta_2}$, the covariance term, is calculated in the following manner:

$$\sigma_{\beta_1\beta_2} = \frac{\beta_1}{(\sum_{i=1}^n (x_i - \overline{x})^2)^2}\sum_{i=1}^n (x_i - \overline{x})(y_i - \overline{y})[(y_i - \overline{y}) - \beta_1(x_i - \overline{x})][(y_i - \overline{y}) - \beta_2(x_i - \overline{x})] \tag{A6}$$

where $\overline{x}$ and $\overline{y}$ are the sample means and $n$ is the number of data points.

Since the covariance depends explicitly on the coordinates of the data points in the sample, it is not obvious how to calculate it in the presence of censoring. We estimated the magnitude of the covariance term for all of the samples of data points, treating the upper limits as detections, in order to see if this term could be neglected in the calculation of the bisector slope uncertainty. We found that typically the covariance term is much smaller than the other two terms which are included in the expression for the bisector slope uncertainty. Thus, we decided to approximate the bisector slope uncertainty as:

$$\sigma^2_{\beta_{bis}} \approx \sigma^2_{\beta_1} (\frac{\partial \beta_{bis}}{\partial \beta_1})^2 + \sigma^2_{\beta_2} (\frac{\partial \beta_{bis}}{\partial \beta_2})^2 \tag{A7}$$

The plots themselves (fig. 4) offer a visual representation of the uncertainty of each bisector slope, which depends on the strength of the correlation between the two variables. The stronger the correlation, the smaller the angle between the two regressions, and the better-defined the bisector slope.

## A. 3. Results of Spearman Partial Rank Tests

Tables 11A, B, C, and D list the results of the Partial Rank analysis applied to each pair of variables for the total sample and the three subsamples.

## REFERENCES


Aaronson M., Huchra, J., Mould, J. 1979, ApJ, 229, 1.

Aaronson, M., Dawe, J.A., Dickins, R.J., Mould, J.R., Murray, J.B. 1981, MNRAS, 195, 1P

Aaronson M., Huchra, J., Mould, J., Tully, R.B., Fisher, J.B., Van Woerden, H., Goss, W.M., Chamaraux, P., Mebold, U., Siegman, B., Berriman, G., Persson, S.E. 1982, ApJS, 50, 241.

Ajhar, E.A., Lauer, T.R., Tonry, J.L., Blakeslee, J.P., Dressler, A., Holtzman, J.A. & Postman, M. 1997, AJ, 114, 626

Allen, C.W. 1973, Astrophysical Quantities (London: The Athlone Press), p.197.

Allen, D.A. 1976, ApJ, 207, 367

Balzano, V.A., Weedman, D.W. 1981, ApJ, 243, 756

Becker, R.H., White, R.L., Edwards, A. 1991, ApJS, 75,1

Becklin, E. E., Gatley, I., Matthews, K., Neugebauer, G., Sellgren, K., Werner, M. W., Wynn-Williams, C. G. 1980, ApJ, 236, 441

Beichman, C. A., Neugebauer, G. 1984, Infrared Astronomical Satellite (IRAS) Catalogs and Atlases Explanatory Supplement (Pasadena:JPL)

Böhm-Vitense, E. 1997, AJ, 113, 13

Bothun, G.D., Aaronson, M., Schommer, B., Huchra, J., Mould, J. 1984, ApJ, 278, 475

Bothun, G.D., Aaronson, M., Schommer, B., Mould, J. Huchra, J., Sullivan, W.T. III 1985, ApJS, 57, 423

Colbert, E. J. M. & Mushotzky, R. F. 1999, ApJ, 519, 89

Calvani, M., Fasano, G., Franceschini, A. 1989, AJ, 97, 1319

Condon, J.J. 1980, ApJ, 242, 894

Condon, J.J., Condon, M.A., Gisler, G., Puschell, J.J. 1982, ApJ, 252, 102

Condon, J.J., Frayer, D.T, Broderick, J.J 1991, AJ, 101, 362

Corbelli, E., Salpeter, E., Dickey, J. 1991, ApJ, 370, 49

Côté, S., Freeman, K.C., Carignan, C., & Quinn, P.J. 1997, AJ, 114, 1313.

Cutri, R.M., McAlary, C.W. 1985, ApJ, 296, 90

de Jong, T., Klein, U., Wielebinski, R., Wunderlich, E. 1985, A&A, 147, L6

de Vaucouleurs, A., Longo, G. 1988, Catalogue of Visual and Infrared Photometry of Galaxies From 0.5 $\mu$m to 10 $\mu$m (1961 - 1985) (Austin: University of Texas Press)

deVaucouleurs, G. & Olson, D.W. 1984, ApJS, 56, 91

de Vaucouleurs, G., de Vaucouleurs A., Corwin, H.G. 1976, Second Reference Catalogue of Bright Galaxies (Austin: University of Texas Press) (RC2)

de Vaucouleurs, G., de Vaucouleurs A., Corwin, H.G.jr, Buta, R. J., Paturel, G., Fouque, P. 1991, The Third Reference Catalogue of Bright Galaxies, (New York: Springer) (RC3)

Dickey, J.M., Salpeter, E. E. 1984, AJ, 284, 461

Disney, M.J., Wall, J.V. 1977, MNRAS, 179, 235

Eastman, R.G., Schmidt, B.P. & Kirshner, R. 1996, ApJ, 466, 911

Ekers, R.D., Ekers, J.A. 1973, A&A, 24, 247

Elvis, M., Soltan, A., Keel, W.C. 1984, ApJ, 283, 479

Eskridge, P.B., Fabbiano, G., Kim, D.-W. 1995a, ApJS, 97, 141

Eskridge, P.B., Fabbiano, G., Kim, D.-W. 1995b, ApJ, 442, 523

Eskridge, P.B., Fabbiano, G., Kim, D.-W. 1995c, ApJ, 448, 70

Fabbiano, G. 1989, Ann.Rev.A.Ap., 27, 87.

Fabbiano, G. 1990 in *Windows on Galaxies*, eds. G. Fabbiano, J.S. Gallagher, A. Renzini, p. 231. Dordrecht: Kluwer

Fabbiano, G., Gioia, I.M, Trinchieri, G. 1988, ApJ, 324, 749

Fabbiano, G., Gioia, I.M., Trinchieri, G. 1989, ApJ, 347, 127

Fabbiano, G., Kim, D.-W., Trinchieri, G. 1992, ApJS, 80, 531. (FKT)

Fabbiano, G., Shapley, A. 2001, in preparation (Paper II).

Fabbiano, G., Trinchieri, G. 1985, ApJ, 296, 430

Fabbiano, G., Trinchieri, G. 1987, ApJ, 315, 46.

Feigelson, E.D., Berg, C.J. 1983, ApJ, 269, 400

Feldmeier, J.J., Ciardullo, R. & Jacoby, G.H. 1997, ApJ, 479, 231

Ferguson, H.C. & Sandage, A. 1990, AJ, 100, 1

Forbes, D.A. 1996, AJ, 112, 1409

Freedman, W.L., Hughes, S.M., Madore, B.F., Mould, J.R., Lee, M.G., Stetson, P., Kennicutt, R.C., Turner, A., Ferrarese, L, Ford, H., Graham, J.A., Hill, R., Hoessel, J.G., Huchra, J., & Illingworth, G.D. 1994, ApJ, 427, 628

Freedman, W.L., & Madore, B.F. 1988, ApJ, 332, L63

Freedman, W.L., & Madore, B.F. 1991, PASP, 103, 933

Freedman, W.L., Madore, B.F., Hawley, S.L, Horowitz, I.K., Mould, J., Navarrete, M., & Sallmen, S. 1992, ApJ, 396, 80

Frogel, J.A., Persson, S.E., Aaronson, M., Matthews, K. 1978, ApJ, 220, 75.

Fullmer, L., Lonsdale, C. 1989, Catalogued Galaxies and Quasars Observed in the *IRAS* Survey, Version 2 (Pasadena: JPL)

Gallagher, J, Fabbiano, G. 1990, in *Windows on Galaxies*, eds. G. Fabbiano, J.S. Gallagher, A. Renzini, p.1. Dordrecht: Kluwer

Gallagher, J.S., Hunter, D.A., Gillett, F.C., Rice, W.L. 1991, ApJ, 371, 142.

Gallart, C., Aparicio, A., & Vílchez, J.M. 1996, AJ, 112, 1928

Garcia, A.M. 1993, A&AS, 100, 47

Garcia, A.M., Fournier, A., DiNella, H. & Paturel, G. 1996, A&A, 310, 412

Giacconi, R. et al.1979, ApJ, 230, 540.

Gioia, I.M., Fabbiano, G. 1987, ApJS, 63, 771.

Gioia, I.M., Gregorini, L., Klein, U. 1982, Astron. Ap., 116, 164

Glass, I.S. 1976, MNRAS, 175, 191.

Glass, I.S. 1984, MNRAS, 211, 461.

Glass, I.S., Moorwood, A.F.M. 1985 MNRAS, 214, 429.

Golombek, D., Miley, G.K., Neugebauer, G. 1988, AJ, 95, 26.

Graham, J. A. et al 1997, ApJ, 477, 535

Griersmith, D., Hyland, A.R., Jones, T.J. 1982, AJ, 87, 1106.

Hamuy, M., Phillips, M.M., Suntzeff, N.B., Schommer, R.A., Maza, J. & Aviles, R. 1996, AJ, 112, 2391

Haynes, R. F., Huchtmeir, W. K. G. Siegman, B. C 1975, A compendium of radio measurements of bright galaxies, (Melbourne: Commonwealth Scientific and Industrial Research Organization (CSIRO), Division of Radiophysics)

Heckman, T.M., Lebofsky, M.J., Rieke, G.H., Van Breugel, W. 1983, ApJ, 272, 400.

Helou, G., Khan, I. R., Malek, L., & Boehmer, L. 1988, ApJS, 68, 151

Helou, G., Ryter, C., Soifer, B.T. 1991, ApJ, 376, 505.

Helou, G., Soifer, B.T., Rowan-Robinson, M. 1985, ApJ, 298, L7.

Herrnstein, J. R., Moran, J. M., Greenhill, L. J., Diamond, P. J., Inoue, M., Nakai, N., Miyoshi, M., Henkel, C., & Riess, A. 1999, Nature, 400, 539

Ho, L. C., Filippenko, A. V., & Sargent, W. L. W. 1997, ApJS, 112, 315

Hughes, S.M.G., Han, M., Hoessel, J., Freedman, W.L., Kennicutt, R.C., Jr., Mould, J.R., Saha, A., Stetson, P.B., Madore, B.F., Silbermann, N.A., Harding, P., Ferrarese, L., Ford, H., Gibson, B.K., Graham, J.A., Hill, R., Huchra, J., Illingworth, G.D., Phelps, R. & Sakai, S. 1998, ApJ, 501, 32

Hummel, E., van der Hulst, J.M., Dickey, J.M. 1984, A&A, 134, 207.

Hunter, Gallagher, J.S. III 1985, AJ, 90, 1457.

Isobe, T., Feigelson, E.D., Akritas, M.G., Babu, G.J 1990, ApJ, 364, 104.

Jones, D.L., Terzian, Y., Sramek, R.A. 1981, ApJ, 247, L57.

Karachentsev, I.D., Drozdovsky, I., Kajsin, S., Takalo, L.O., Heinamaki, P., & Valtonen, M. 1997, A&AS, 124, 559

Karachentsev, I.D. & Drozdovsky, I.O. 1998, A&AS, 131, 1

Karachentsev, I.D. & Sharina, M.E. 1997, A&A, 324, 457

Kendall, M., Stuart, A. 1976, The Advanced Theory of Statistics, Vol. 2 (New York: Macmillan)

Kennicutt, R. C. Jr, et al 1998, ApJ, 498, 181

Klein, U. 1986, A&A, 168, 65.

Knapp, G.R., Bies, W.E., Van Gorkom, J.H. 1990, AJ, 99, 476.

Knapp, G.R., Guhathakurta, P., Kim, D.-W., Jura, M. 1989, ApJS, 70, 329.

Knapp, G.R., Gunn, J.E., Wynn-Williams, C.G. 1992, ApJ, 399, 76

Krismer, M., Tully, R.B., & Gioia, I.M. 1995, AJ, 110, 1584

LaValley, M.P., Isobe, T., Feigelson, E.D. 1992, BAAS, 24, 839.

Lonsdale, C. J., Helou, G. 1985, Cataloged Galaxies and Quasars Observed in the IRAS Survey, (Pasadena: JPL).

Lonsdale Persson, C. J., Helou, G. 1987, ApJ, 314, 513.

Luri, X., Gomez, A.E., Torra, J., Figueras, F. & Mennessier, M.O. 1998, A&A, 335, L81

Madore, B.F., & Freedman, W.L. 1998 ApJ, 492, 110

Makarova, L.N., Karachentsev, I.D. & Georgiev, Ts.B. 1997, AstL, 23, 378

Magorrian, J., et al 1998, AJ, 115, 2285

Mould, J., Aaronson, M., Huchra, J. 1980, ApJ, 238, 458.

Mould, J. 1981, PASP, 93, 25.

Palumbo, G.G.C., Fabbiano, G., Fransson, C., Trinchieri, G. 1985, ApJ, 298, 259.

Persson, S.E., Frogel, J.A., Aaronson, M., 1979, ApJS, 39, 61.

Penston, M.V., Penston, M.J., Selmes, R.A., Becklin, E.E., Neugebauer, G. 1974, MNRAS, 169, 357.

Pierce, M.J., McClure, R.D. & Racine, R. 1992, ApJ, 393, 523

Pierce, M.J. & Tully, R.B. 1988, ApJ, 330, 579

Pierce, M.J. 1994, ApJ, 430, 53

Puche, D., & Carignan, C. 1988, AJ, 95, 1025

Rice, W., Lonsdale, C.J., Soifer, B.T., Neugebauer, G., Kopan, E.L., Lloyd, L.A., de Jong, T., Habing, H.J. 1988, ApJS, 68, 91.

Rieke, G., H., 1978, ApJ, 226, 550.

Riess, A.G., Press, W.H. & Kirshner, R.P. 1996, ApJ, 473, 88

Roberts, M.S., Hogg, D.E., Bregman, J.N., Forman, W.R., Jones, C. 1991, ApJS, 75, 751.

Ryder, S.D., Staveley-Smith, L., Malin, D. & Walsh, W. 1995, AJ, 109, 1592

Saha, A., Labhardt, L., Schwengeler, H., Macchetto, F.D., Panagia, N., Sandage, A. & Tammann, G.A. 1994, ApJ, 425, 14

Saha, A., Sandage, A., Labhardt, L., Schwengeler, H., Tammann, G.A., Panagia, N. & Macchetto, F.D. 1995, ApJ, 438, 8

Saha, A., Sandage, A., Labhardt, L., Tammann, G.A., Macchetto, F.D., & Panagia, N. 1996, ApJ, 466, 55

Sandage, A., Saha, A., Tammann, G.A., Labhardt, L., Panagia, N. & Macchetto, F.D. 1996, ApJ, 460, L15

Sandage, A., & Tammann, G. A. 1987, A Revised Shapley-Ames Catalog of Bright Galaxies (2nd ed., Washington, DC: Carnegie Institution of Washington)(RSA)

Schmidt, B.P., Kirshner, R.P., Eastman, R.O., Phillips, M.M., Suntzeff, N.B., Hamuy, M., Maza, J. & Aviles, R. 1994, ApJ, 432, 42

Schmitt, J.H.M.M. 1985, ApJ, 293, 178.

Schöniger, F. & Sofue, Y. 1994, A&A, 283, 21

Schöniger, F. & Sofue, Y. 1997, A&A, 323, 14

Shanks, T. 1997, MNRAS, 290, L77

Sharina, M.E., Karachentsev, I.D. & Tikhonov, N.A. 1996, A&AS, 119, 499

Sohn, Y.-J. & Davidge, T.J. 1996, AJ, 112, 25

Sramek, R. 1975, AJ, 80, 771.

Stetson, P. B. et al 1998, ApJ, 508, 491

Stocke, J.T., Tifft, W.G., Kaftan-Kassim, M.A 1978, AJ, 83, 322.

Sulentic, J.W. 1976, ApJS, 32, 171.

Teerikorpi, P., Bottinelli, L., Gouguenheim, L. & Paturel, G. 1992, A&A, 260,

Telesco, C.M., Harper, D.A. 1980, ApJ, 235, 392

Theureau, G., Hanski, M., Ekholm, T., Bottinelli, L., Gouguenheim, L., Paturel, G. & Teerikorpi, P. 1997, A&A, 322, 730

Thuan, T.X. 1983, ApJ, 268, 667.

Tikhonov, N.A. & Karachentsev, I.D. 1998, A&AS, 128, 325

Tolstoy, E., Saha, A., Hoessel, J.G., & McQuade, K. 1995, AJ, 110, 1640

Tormen, G., & Burstein, D. 1995, ApJS, 96, 123

Trinchieri, G., Fabbiano, G. 1991, ApJ, 382, 82.

Trinchieri, G., Fabbiano, G., Bandiera, R. 1989, ApJ, 342, 759 (TFB).

Trinchieri, G., Fabbiano, G., Peres, G. 1988, ApJ, 325, 531.

Trinchieri, G., Fabbiano, G., Romaine, S. 1990, ApJ, 356, 110.

Tully, B.R, Mould, J. R. & Aaronson, M. 1982, ApJ, 2557, 527.

Tully, B.R. 1988, Nearby Galaxies Catalog (New York: Cambridge University Press)

Tutui, Y. & Sofue, Y. 1997, A&A, 326, 915

Ulvestad, J.S., Wilson, A.S., Sramek, R.A. 1981, ApJ, 247, 419.

Ulvestad, J.S., Wilson, A.S., 1984, ApJ, 285, 439.

Ulvestad, J.S., Wilson, A.S., 1989, ApJ, 343, 659.

Ward, M., Allen, D.A., Wilson, A.S., Smith, M.G., Wright, A.E. 1982, MNRAS, 199, 953.

Whiteoak, J.B. 1970, Astrophys. Lett., 5, 29.

Whitmore, B.C. 1984, ApJ, 278, 61.

Willick, J. A., Courteau, S., Faber, S. M., Burstein, D., Dekel, A., Kolatt, S. 1996, ApJ, 457, 460.

Willner, S.P., Elvis, M., Fabbiano, G., Lawrence, A., Ward, M. J. 1985, ApJ, 299, 443.

Wilson, A.S., Ulvestad, J.S. 1982, ApJ, 260, 56.

Wright, A.E. 1974, MNRAS, 167, 273.

Wunderlich, E., Wielebinski, R., Klein, U. 1987, A & AS, 69, 487.

Wunderlich, E., Klein, U. 1991, A & AS, 87, 247.

Yahil, A., Tammann, G.A., & Sandage, A. 1977, ApJ, 217, 903.

Yasuda, N., Fukugita, M. & Okamura, S. 1997, ApJS, 108, 417

Young, J.S. in *Windows on Galaxies*, eds. G. Fabbiano, J.S. Gallagher, A. Renzini, p. 213, Dordrecht: Kluwer.

This preprint was prepared with the AAS LaTeX macros v4.0.

Fig. 1.— Distribution of absolute magnitudes for the sample galaxies.

Fig. 2.— Distribution of sample galaxies in morphological types (T). The unshaded regions denote the galaxies flagged as AGN.

Fig. 3.— Comparison of our calculated $H_{0.5}$ with those of Tormen & Burstein (1995).

Fig. 4.— Distributions of X-ray luminosities in the Total sample and the three morphological subsamples (‘Early’, T=0-2; ‘Intermediate’, T=3-4; and ‘Late’, T=5-10). For comparison we also show the distribution of $L_X$ for the FKT E and S0 galaxies. In all diagrams, except the T=0-2 one, the shaded area represents detections, the unshaded area represents upper limits. In the T=0-2 diagram different levels of shading represent: unshaded – S0/a-Sab upper limits; light shading – S0/a-Sab detections; heavier shading – Amorphous upper limits; solid shading – Amorphous detections.

Fig. 5.— Distributions of $L_X/L_B$ in the Total sample and the three morphological subsamples (‘Early’, T=0-2; ‘Intermediate’, T=3-4; and ‘Late’, T=5-10). For comparison we also show the distribution of $L_X/L_B$ for the FKT E and S0 galaxies. Same shading conventions as in fig. 2.

Fig. 6.— Scatter diagrams for luminosity pairs. For each pair, the scatter diagrams for the Total sample and for the three morphological subsamples (‘Early’, T=0-2; ‘Intermediate’, T=3-4; and ‘Late’, T=5-10) are plotted. Filled squares identify detections on both axes; triangles identify upper limits in one of the axis, with the apex pointing in the direction of the limit; empty circles identify upper limits in both axes; circles surrounding another symbol identify the flagged AGN, which were not included in the statistical analysis; squares surrounding another symbol identify Amorphous galaxies, which were not included in the T=0-2 analysis. The solid lines across the points represent the regression bisectors, while individual regressions are represented by the two dashed lines.

Fig. 7.— Scatter diagrams of Log($L_X/L_B$) versus other luminosity ratios. For each pair, the scatter diagrams for the Total sample and for the three morphological subsamples (‘Early’, T=0-2; ‘Intermediate’, T=3-4; and ‘Late’, T=5-10) are plotted. Filled squares identify detections on both axes; triangles identify upper limits in one of the axis, with the apex pointing in the direction of the limit; empty circles identify upper limits in both axes; circles surrounding another symbol identify the flagged AGN, which were not included in the statistical analysis; squares surrounding another symbol identify Amorphous galaxies, which were not included in the T=0-2 analysis.

Fig. 8.— Log($L_X$) – Log(D) scatter diagram for the Total sample. Circles are AGN detections, squares are detections, and triangles are upper limits.

Fig. 9.— Log($L_X$) – Log($L_{6cm}$) scatter diagrams for the Total (a) and Late T=5-10 sample (b). Different symbols are used for different galaxy diameters; see fig. 9a. We do not detect any evident displacement of large diameter galaxies.

Fig. 10.— Graphical representation of the Partial Spearman Rank analysis. Significant correlations are represented by lines connecting the variables, with a greater number of connecting lines identifying relatively stronger correlations. Detailed test results are given in Table 8. We show diagrams for the three morphological subsamples (‘Early’, T=0-2; ‘Intermediate’, T=3-4; and ‘Late’, T=5-10) and for the total sample.

Fig. 11.— Fractional difference between YTS and CMB corrected Hubble flow velocities versus the YTS velocity